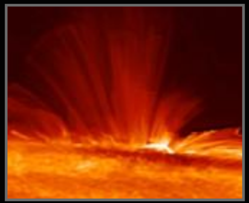
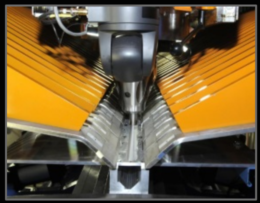
National Aeronautics and Space Administration

NASA's Exploration Systems Development

October 22, 2015







marshall

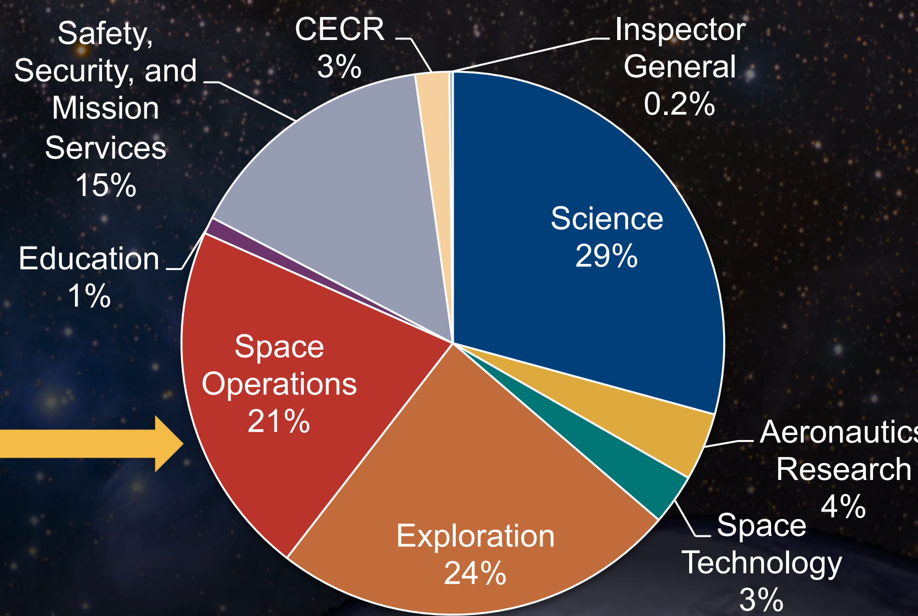
Dr. Paul McConnaughey
Associate Director, Technical
NASA/MSFC

Agenda

- **INTRODUCTION**
- **EXPLORATION SYSTEMS DEVELOPMENT**
  - SLS
  - Orion
  - Ground Systems Development and Operations
  - Exploration Mission-1 and Exploration Mission-2
- **THE PROVING GROUND**
- **EVOLVABLE MARS CAMPAIGN**
  - Trades
  - Mission Concept
  - Technologies
- **SUMMARY**

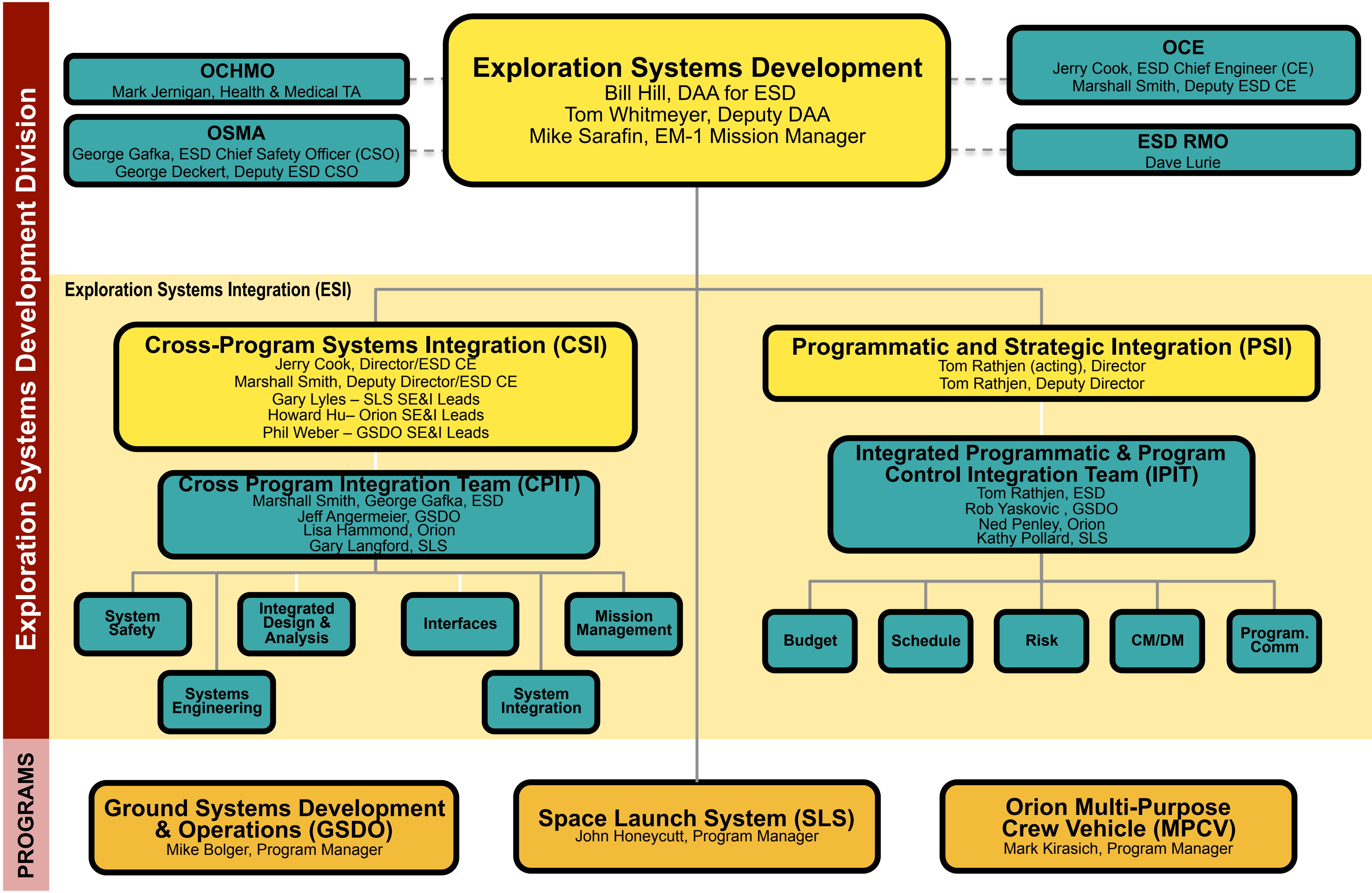
National, NASA, and Marshall Budgets

	FY2013 $3.8T	FY2014 $3.8T	FY2015 $3.9T	FY2016 $4.0T
Requested	$17.7B	$17.7B	$17.5B	$18.5B
Enacted	$17.5B	$17.6B	$18B	TBD
Requested 	$2.2B	$2.2B	$2.1B	$2.1B
Enacted	$2.3B	$2.3B	$2.5B (projected)	TBD

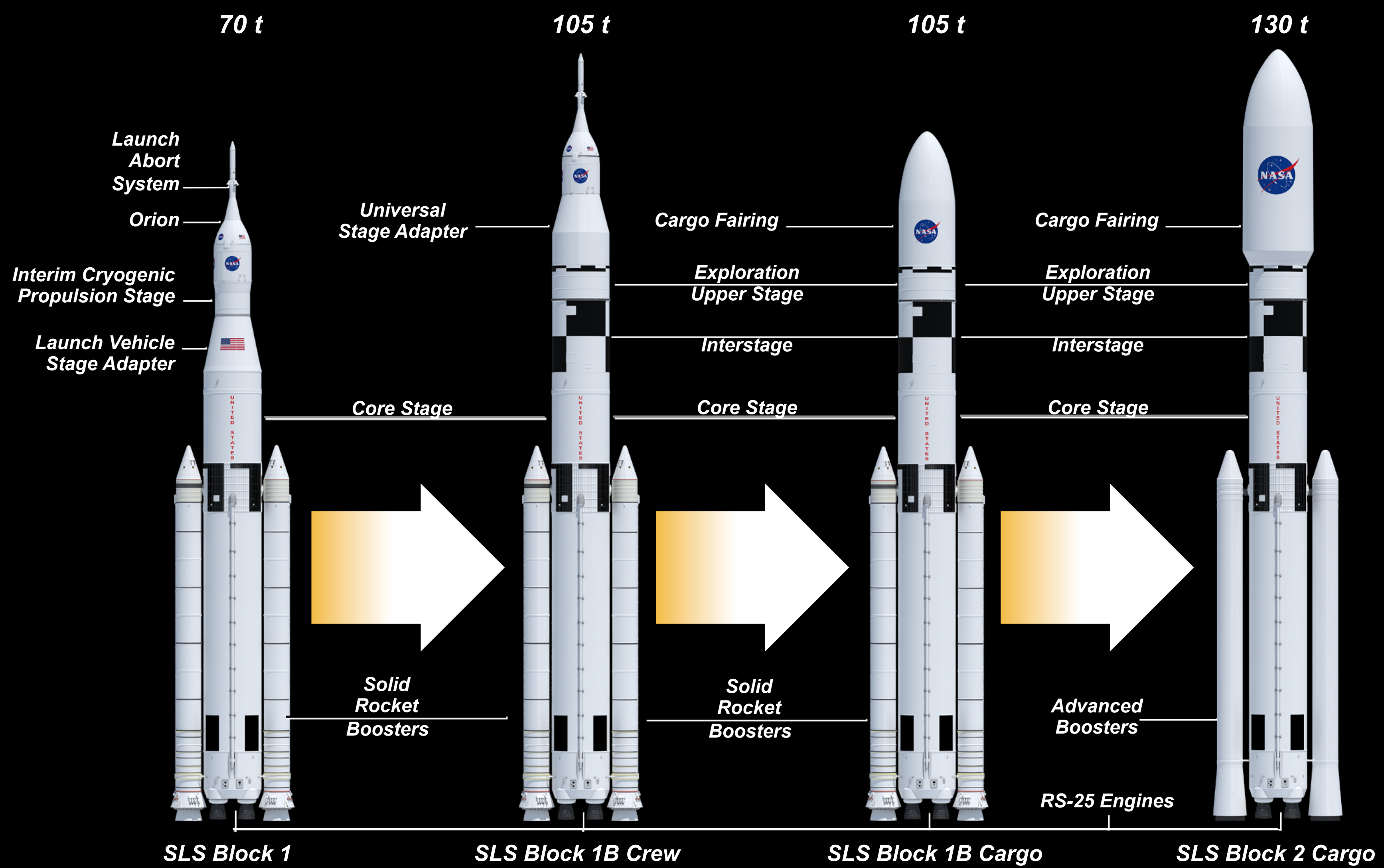


NASA is 0.4% of USG Budget
(10% of NASA budget during Apollo)

Exploration Systems Development Organization



SLS Block 1A and 1B



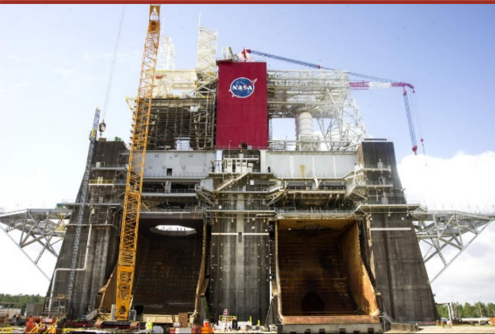
Solid Rocket Boosters

- Overview
  - World’s most powerful solid boosters for flight
  - Two Space Shuttle-heritage solid rocket boosters
  - Upgraded with fifth propellant segment to 3.6 million pounds of thrust capability
- Status
  - First Qualification Motor test completed in March 2015; second scheduled for spring 2016.
  - Flight hardware in inventory at Kennedy Space Center; processing underway at Orbital ATK in Utah.

RS-25 Core Engines

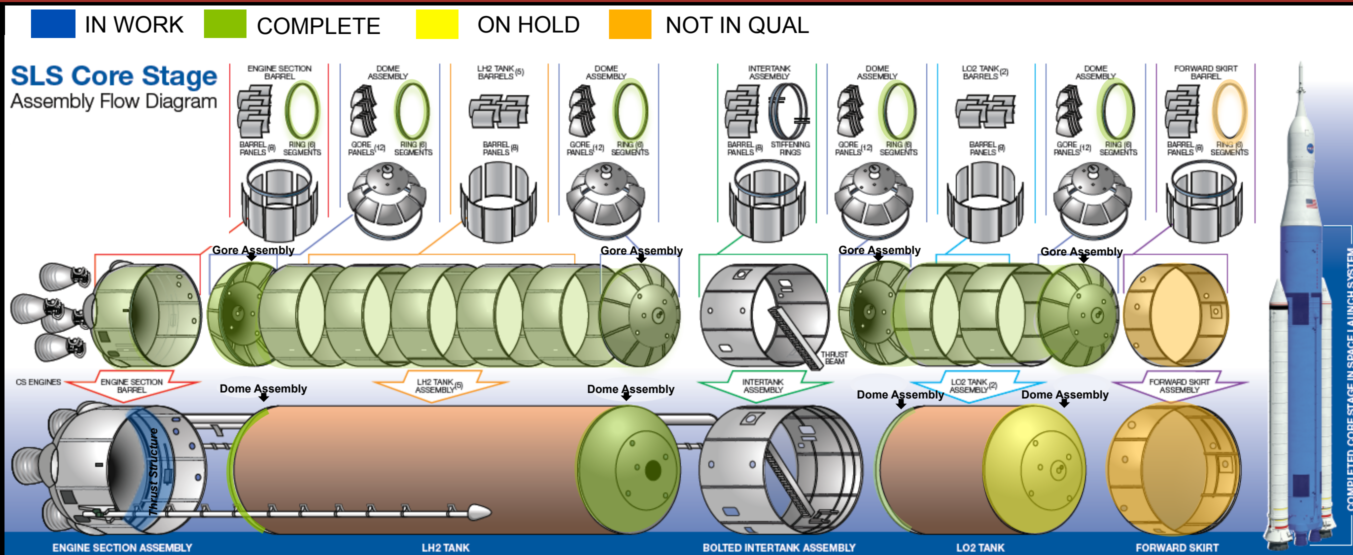
- Overview
  - World's most powerful efficient and reliable liquid rocket engine
  - Four Space Shuttle-heritage RS-25s
  - Upgraded with new controller; engines certified at 418K pounds of thrust each
- Status
  - Sixteen flight engines currently in inventory.
  - First test series completed in August 2015 at Stennis Space Center.

Core Stage



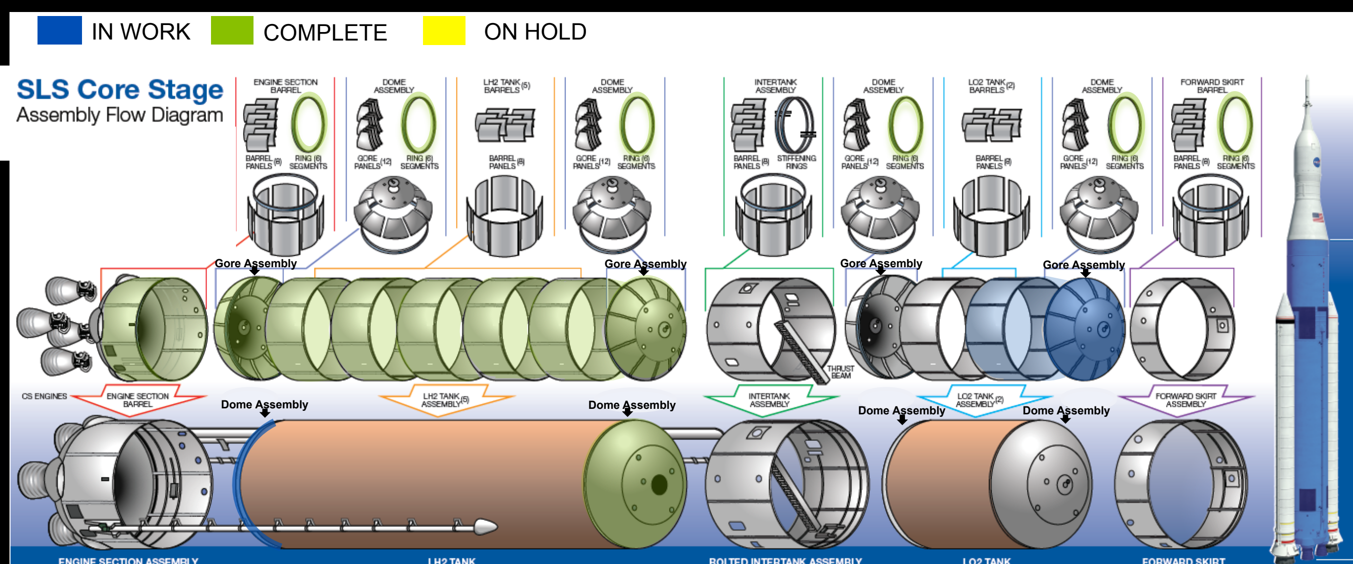
- Overview
  - World's largest rocket stage
  - 27.6 foot diameter; 200 feet tall without engines
  - Being built at the Michoud Assembly Facility outside New Orleans, La.
- Status
  - Welding begins in late 2015 on core stage hydrogen and oxygen tanks.
  - Refurbishment underway on B1 stand at Stennis for Green Run core stage test.

Core Stage Hardware Progress at MAF



Qual Hardware

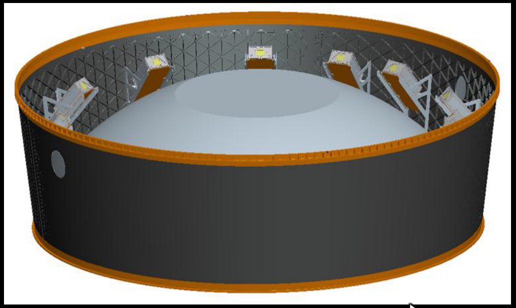
Flight Hardware



Upper Stage and Adapters

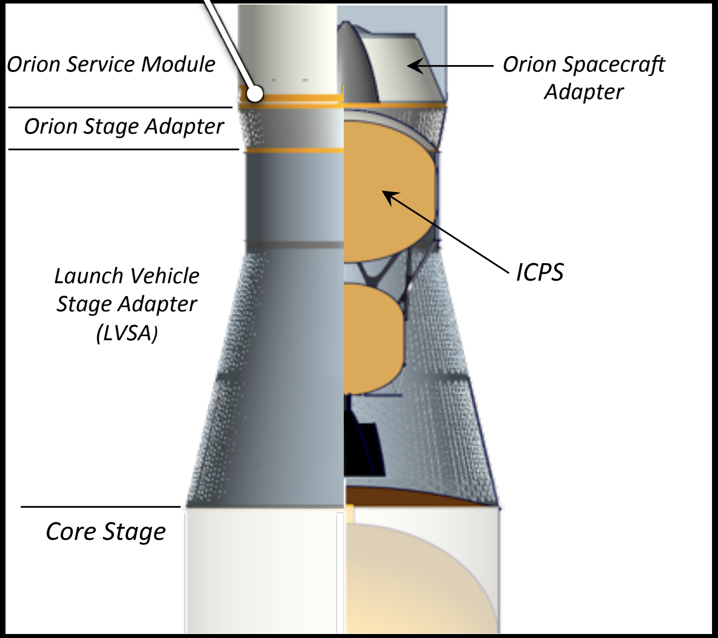
- Overview
  - Interim Cryogenic Propulsion Stage is derived from proven second stage of Delta IV Heavy
  - Launch Vehicle Stage Adapter and Orion Stage Adapter mate ICPS to core stage and Orion, respectively
- Status
  - Orion Stage Adapter became first original SLS hardware to fly on Exploration Flight Test-1 in December 2014.
  - Structural test articles in manufacture currently; will begin stacking for testing in early 2016.

EM-1 Secondary Payloads and Stage Adapter



- SMD: 2 payloads
- STMD Centennial Challenges: 3 payloads
- JAXA: 1 payload (1 potential)
- ESA/UKSA: 1 payload

- 13 total payloads for EM1



SLS: Path to the Pad

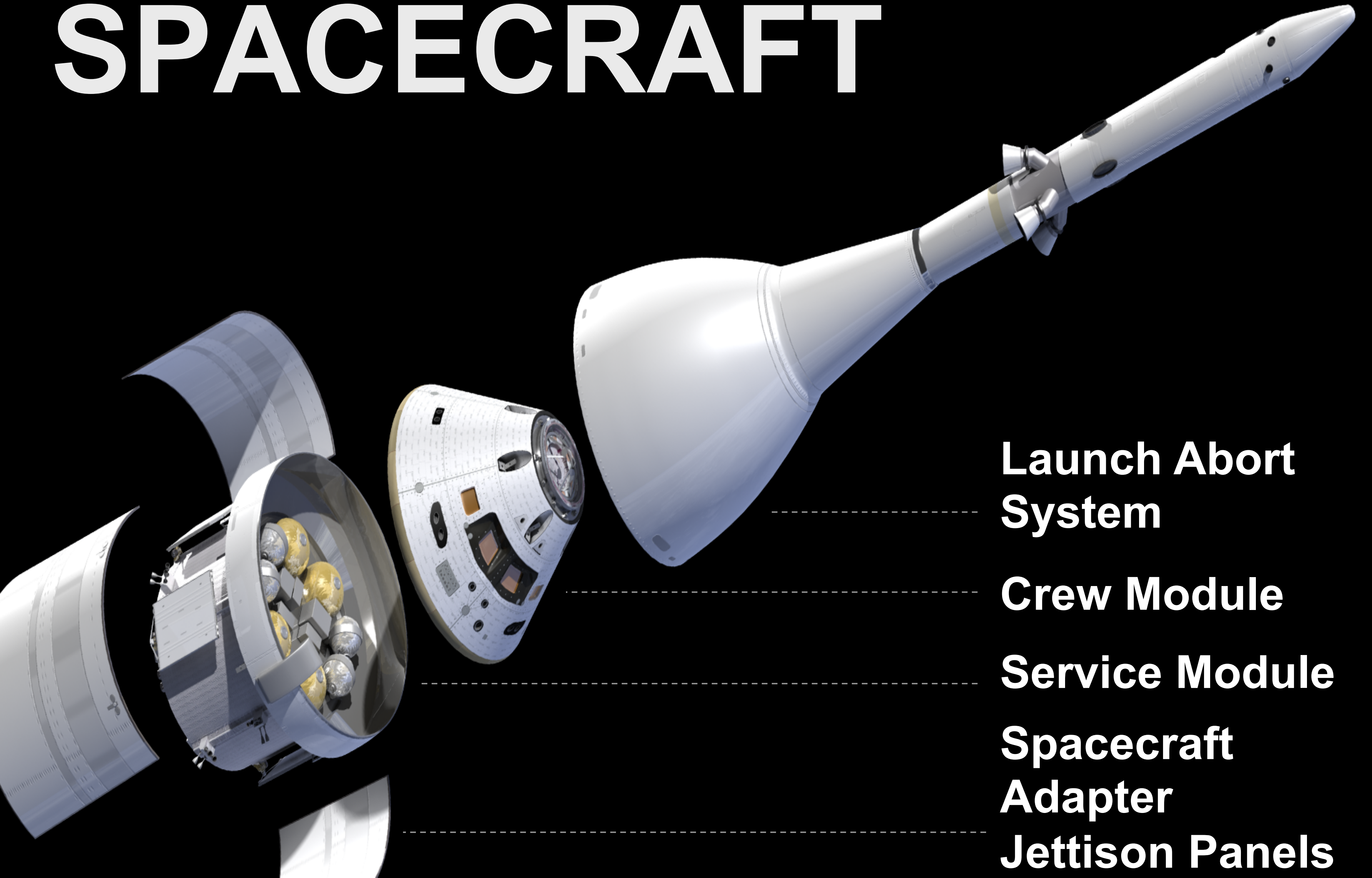
- Qualification Motor 2 (QM-2) test, set for spring 2016, will officially qualify the booster ready to fly.
- Fabrication of the Boosters for first flight will be completed in 2017 and ship to Kennedy Space Center for assembly.
- Development and flight engine testing will resume in 2016.
- Core Stage assembly will begin soon and are on track for completion in 2016.
- Structural Test Article (STA) Test Stands construction is underway and on schedule for completion in the summer of 2016.
- Core Stage STAs will be qualified on the new STA test stands in 2017.
- The assembled Core Stage and engines will be tested at Stennis Space Center in 2017.
- Upper Stage production is underway and Structural Test article testing will occur in 2016.

QM-2 Test

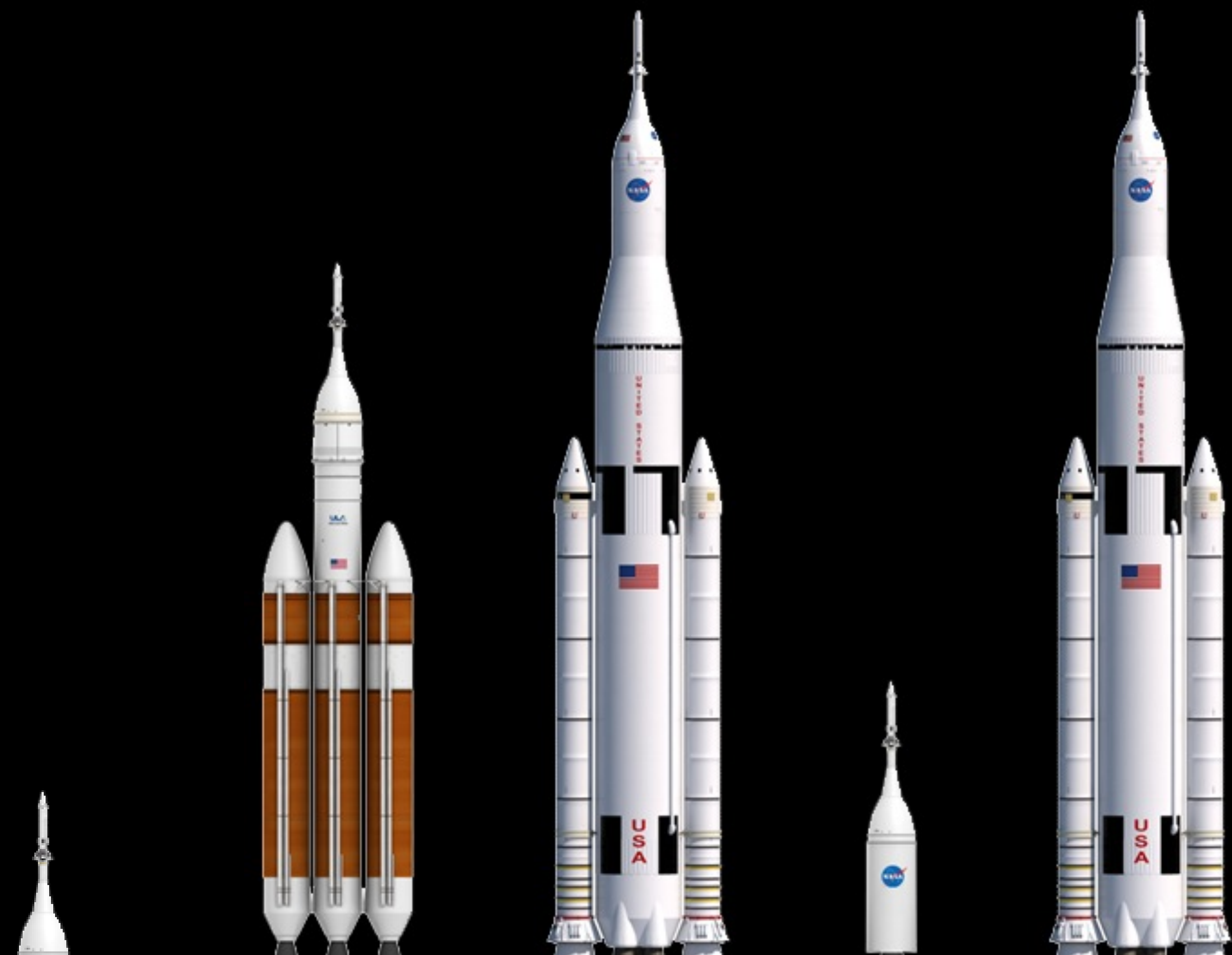
STA Test Stands at MSFC

RS-25 Test Series

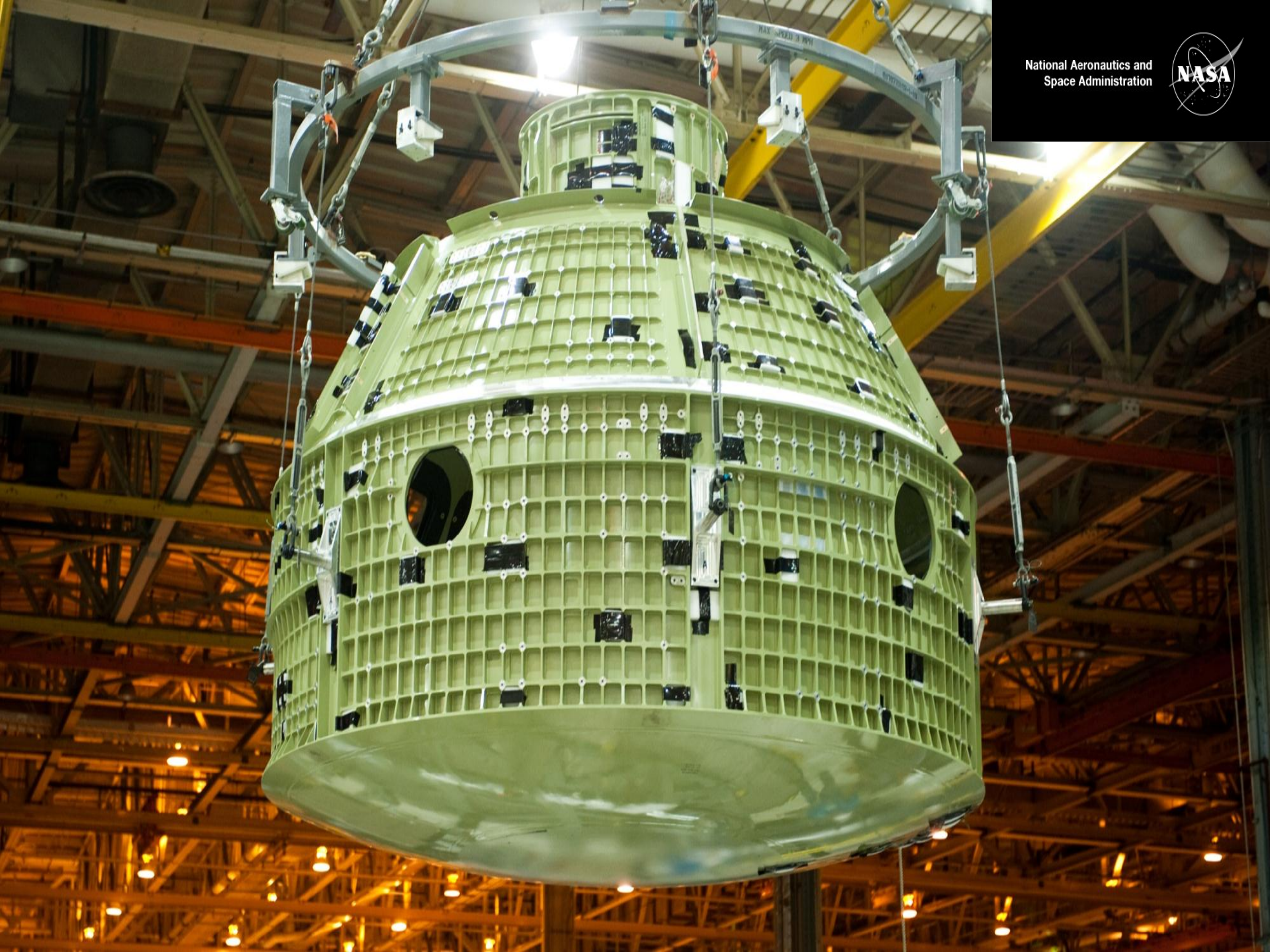
ORION SPACECRAFT



Exploration Mission Timeline



May 2010 PA-1 | ***Dec. 2014 EFT-1*** | EM-1 | AA2 | EM-2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NASA

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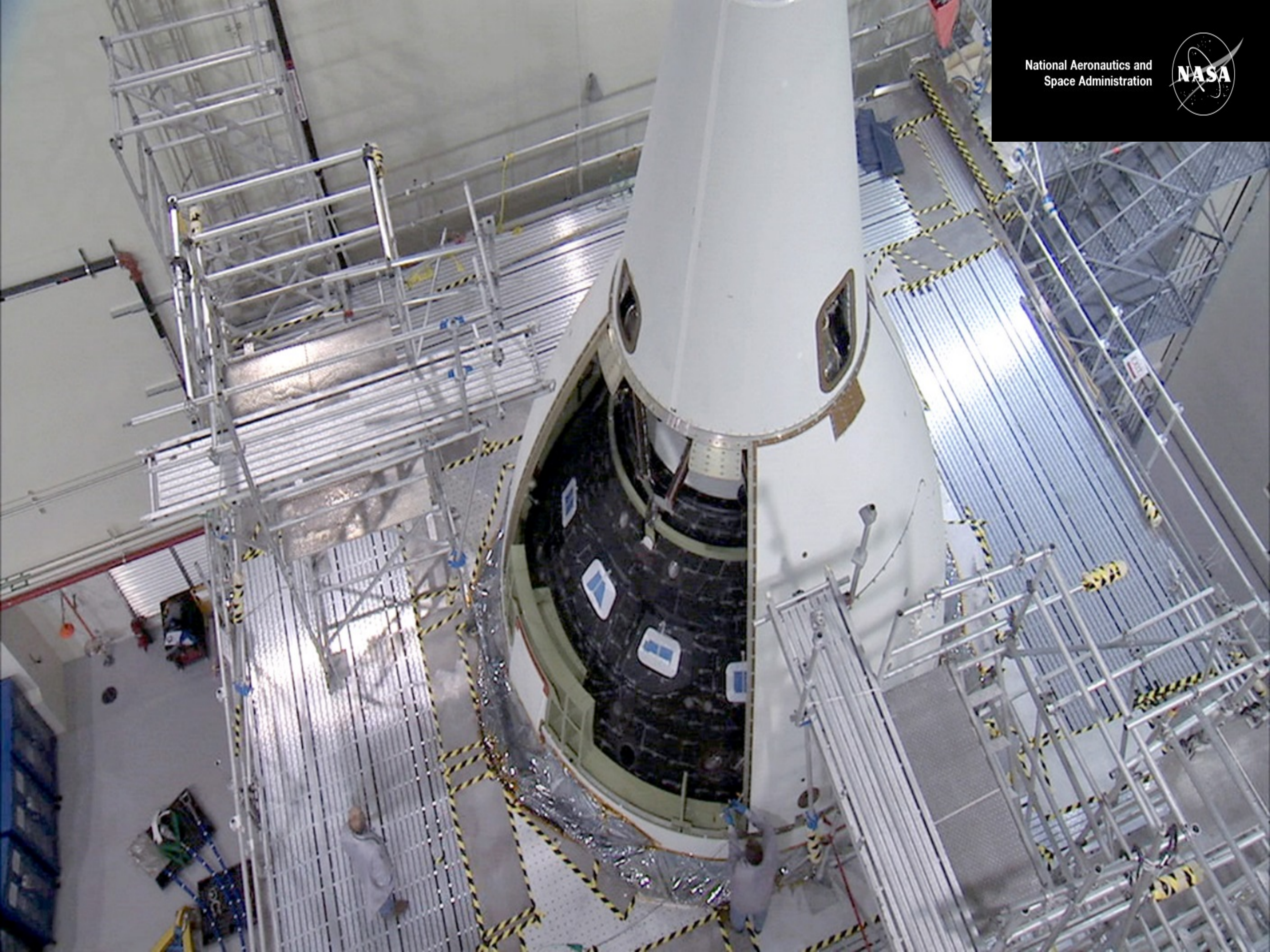
NASA
1000 LBS MAX CONC LOAD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NASA
ULA

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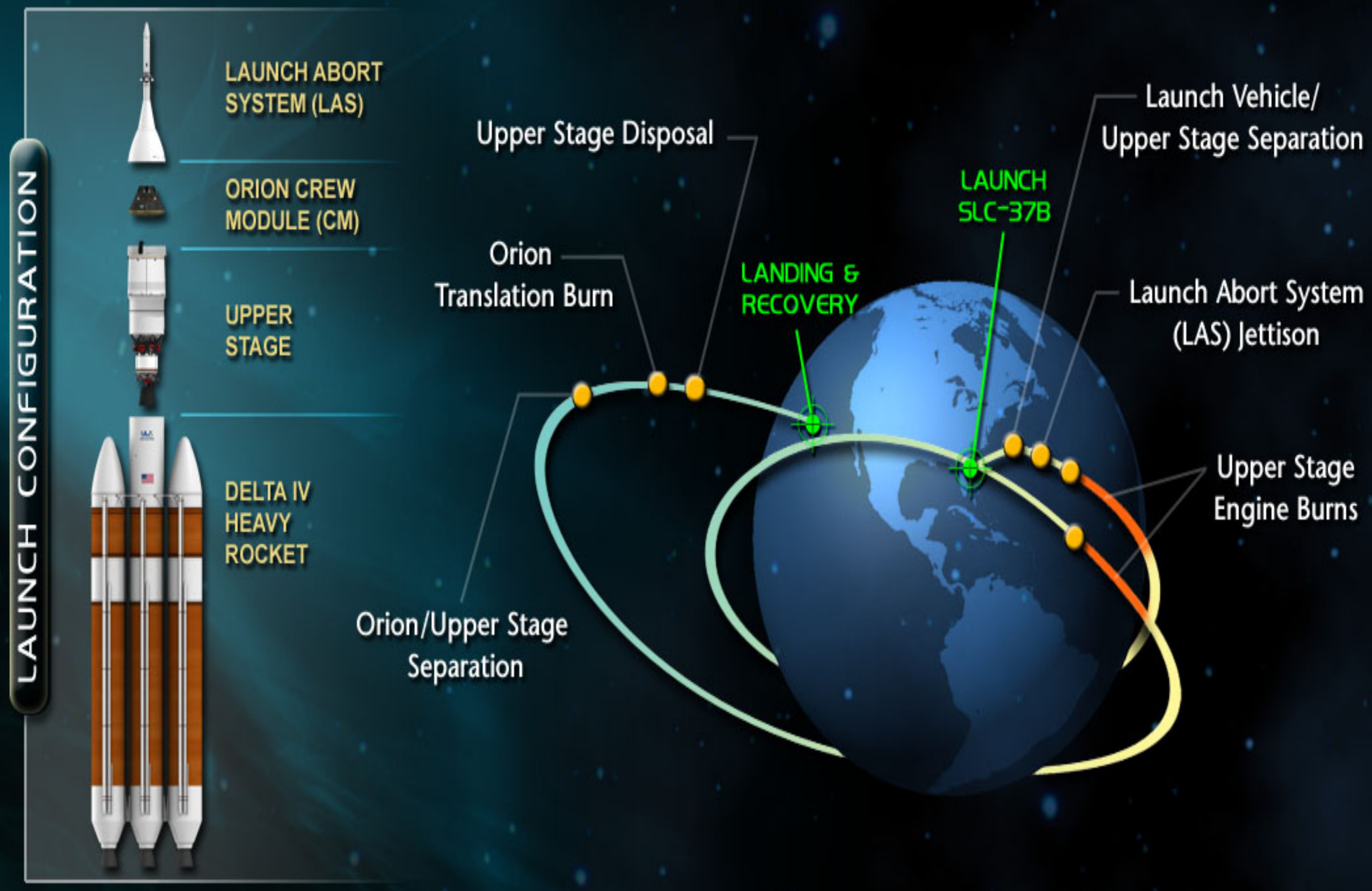
EXPLORATION FLIGHT TEST ONE

OVERVIEW

TWO ORBITS • 20,000 MPH ENTRY • 3,671 MILE APOGEE • 28.6 DEGREE INCLINATION



National Aeronautics and Space Administration

SEPARATION EVENTS

17 Events

Start 6 minutes after launch

Continue throughout the flight

HEAT SHIELD

1.6 inches thick

Mass erodes by 20% during reentry

RADIATION

Vehicle travels 15 times farther than ISS

Flight passes through Van Allen radiation belts

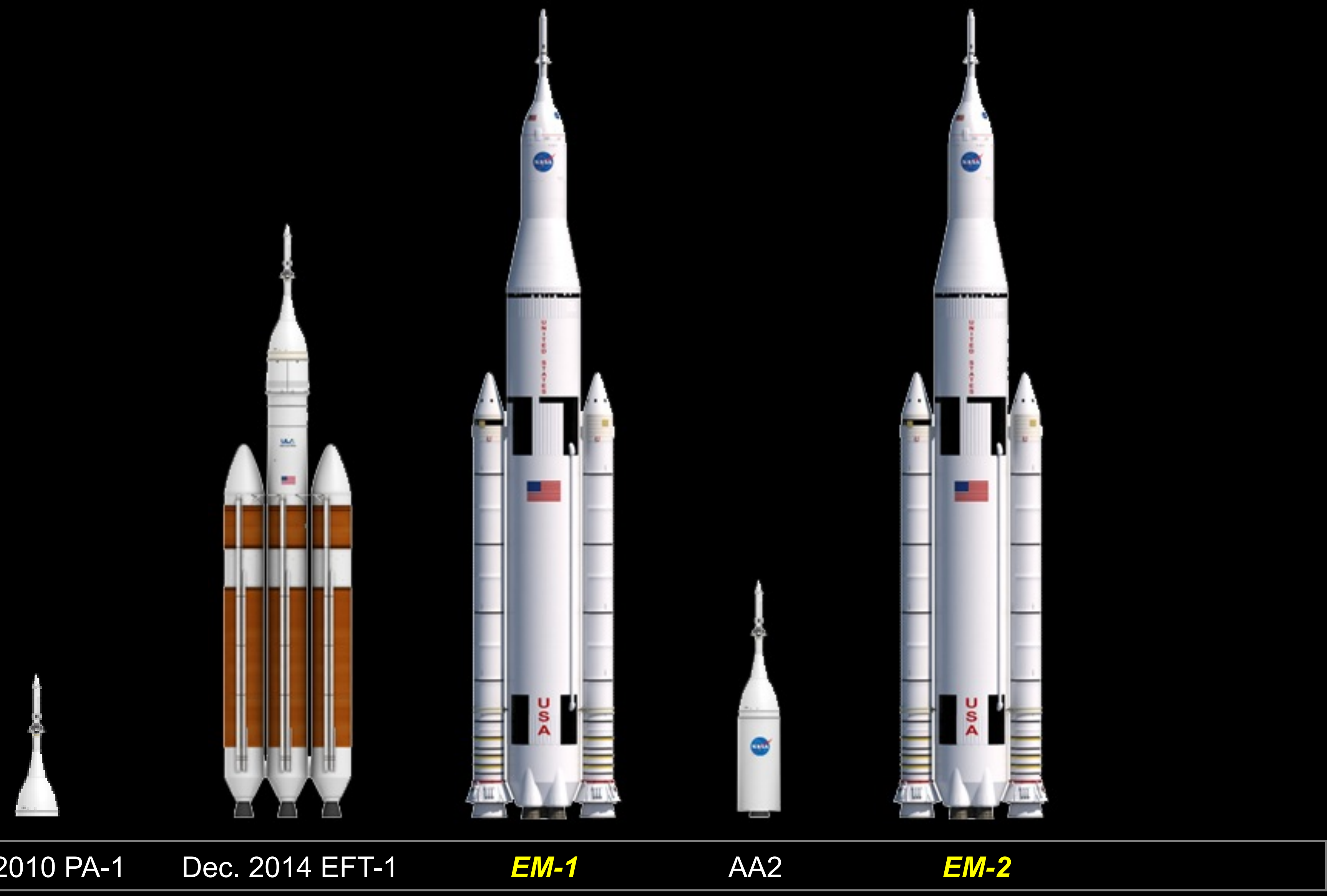
PARACHUTES

Vehicle must slow down from 20,000 MPH to 20 MPH

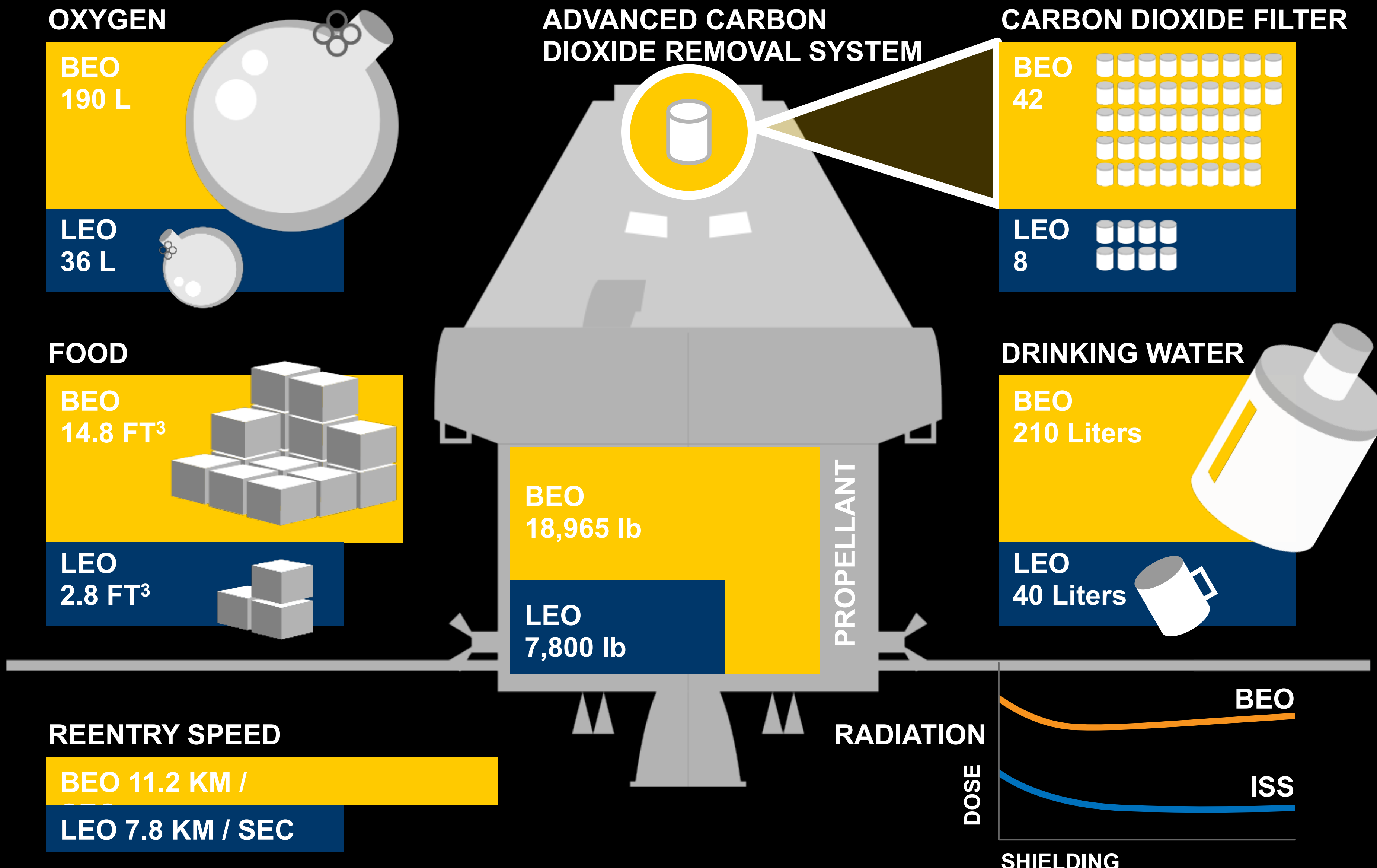
11 Parachutes total, 8 for crew module

Deployment starts at 300 MPH

Exploration Mission Timeline

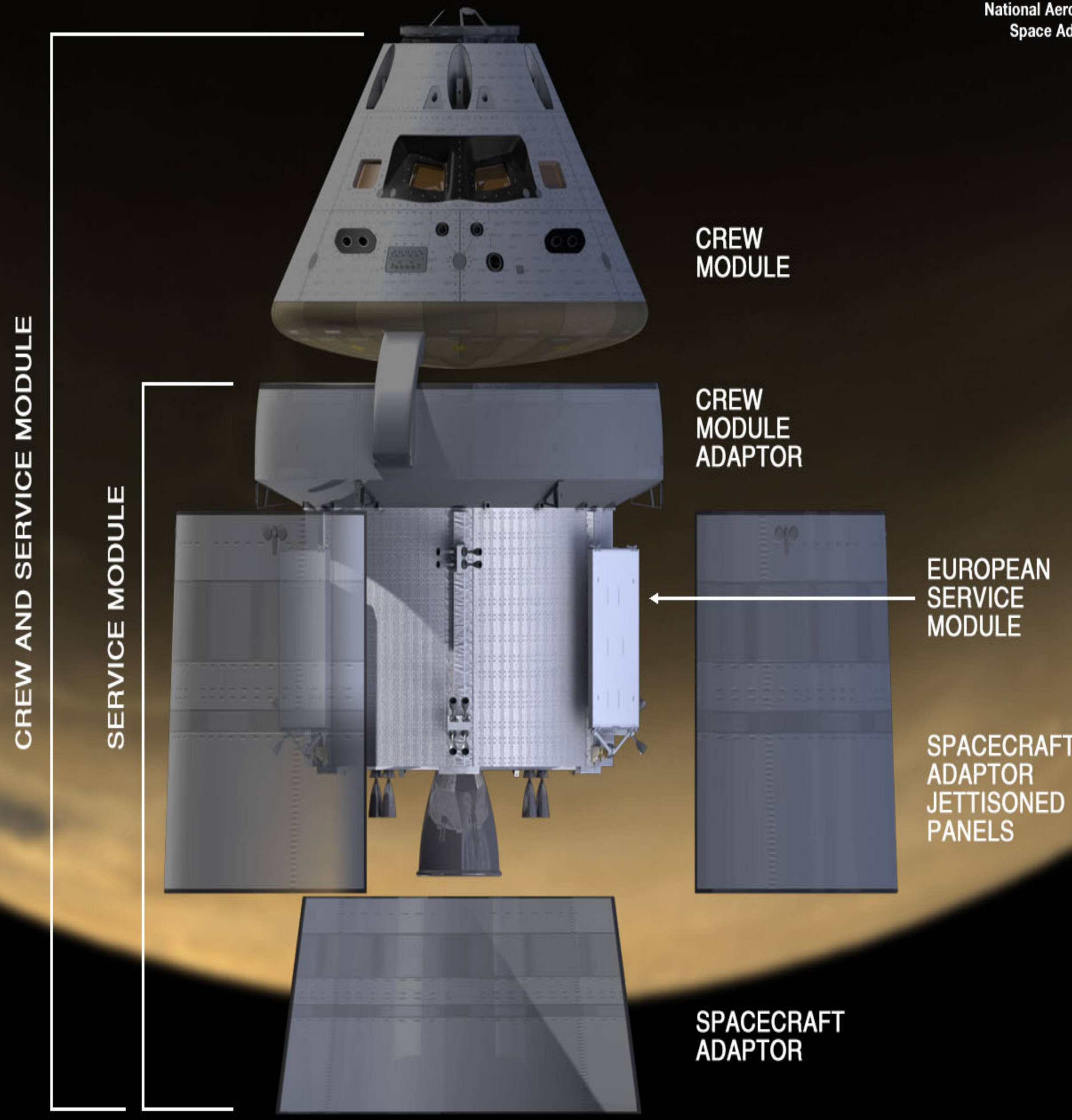


Built for Going Beyond Earth Orbit



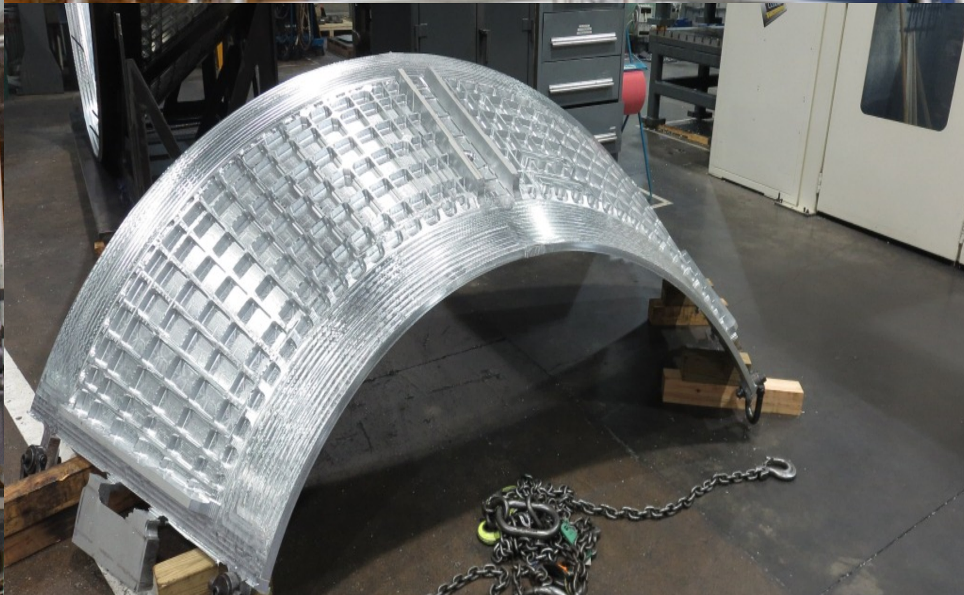
Orion Service Module

National Aeronautics and Space Administration



First Pathfinder Weld

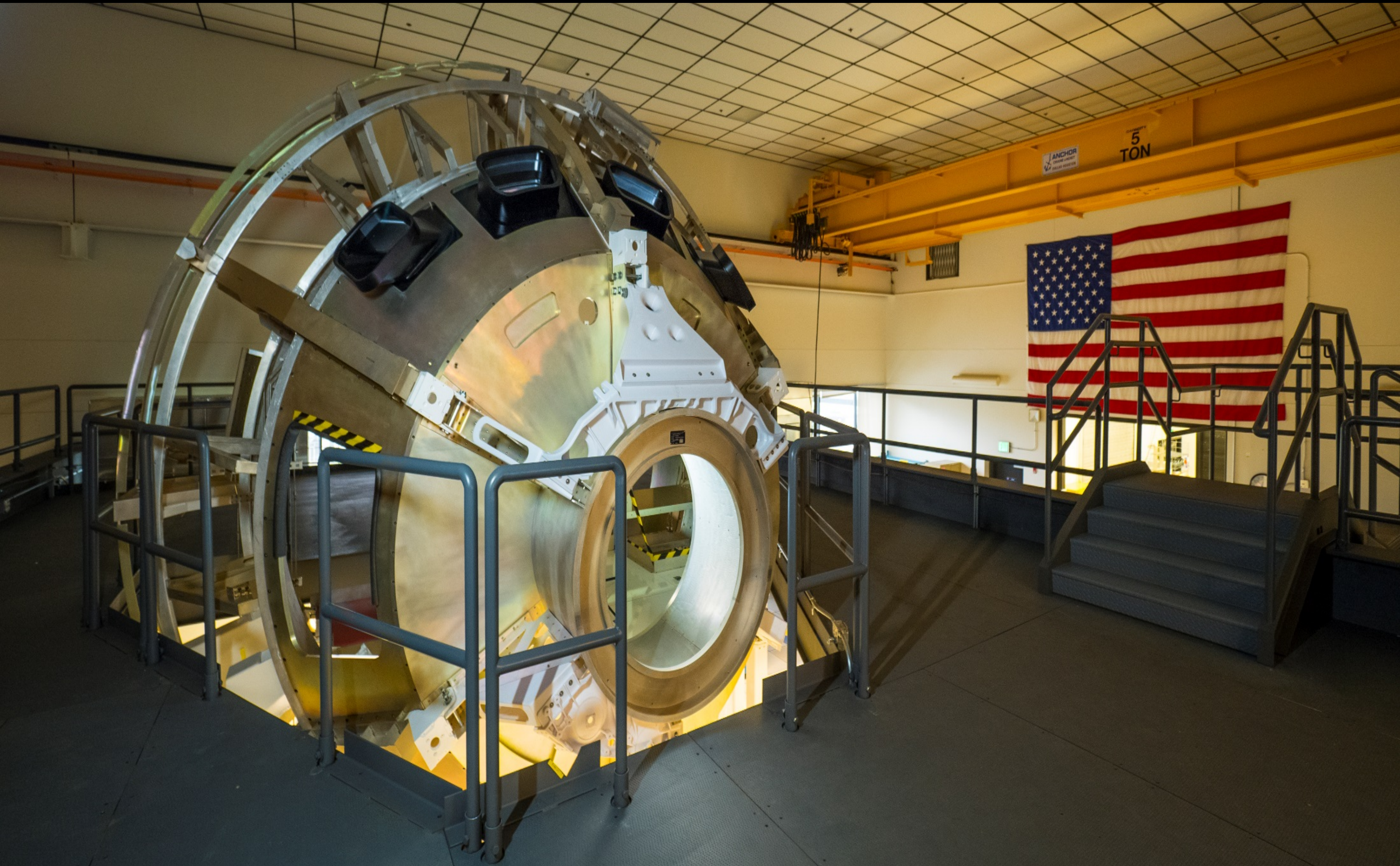
EM-1 Flight Hardware



Orion Launch Abort System

ESA SM Structural Testing

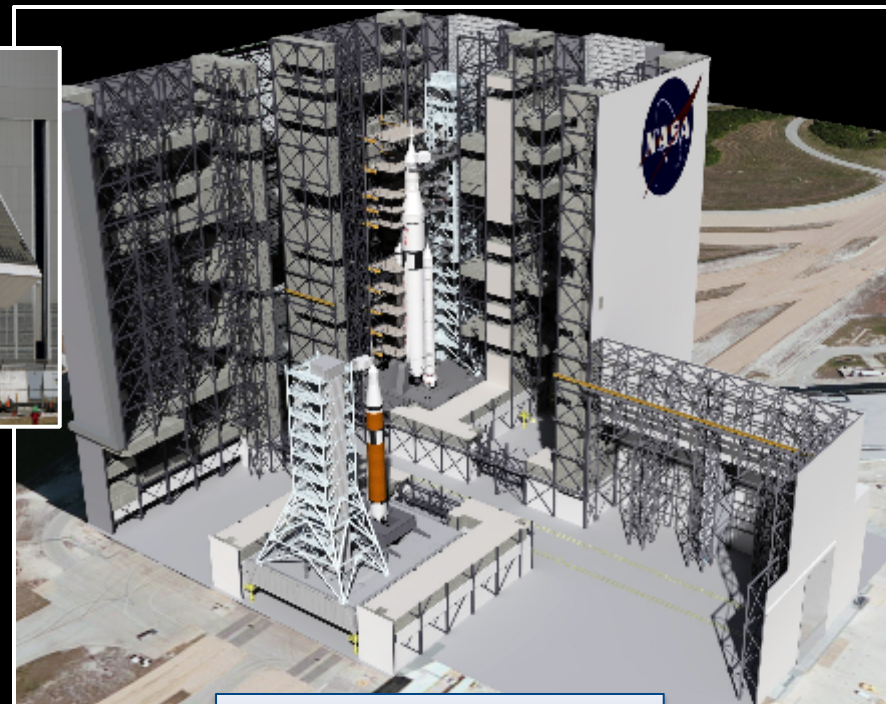
Integrated Test Lab Mockup



Ground Systems Development and Operations

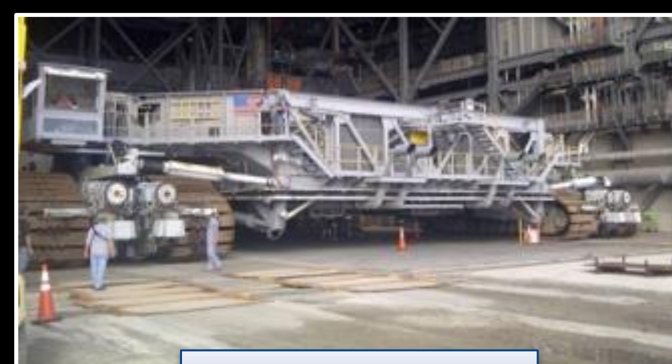
Mobile Launcher

Launch Control



Vehicle Assembly Building

Launch Complex Pad 39B

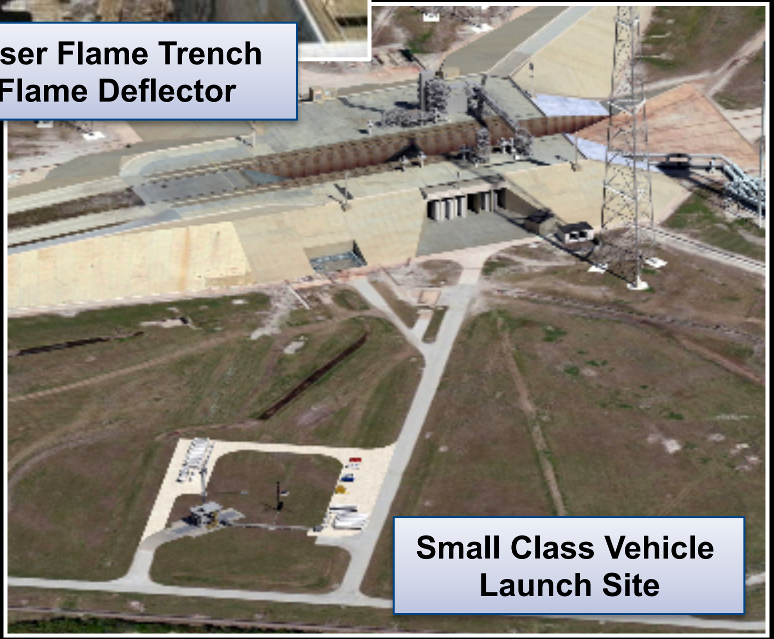


Crawler Transporter

Ground Systems Progress

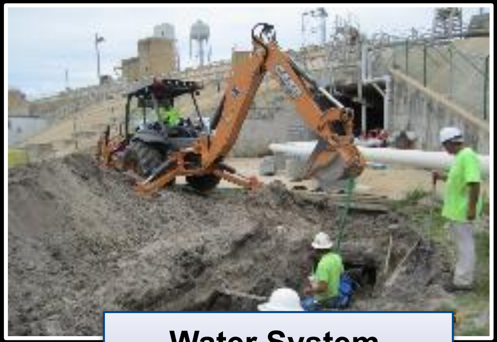
PAD 39B

Multi-user Flame Trench and Flame Deflector



Small Class Vehicle Launch Site

Clean Pad and New Lightning Towers



Water System Upgrade

Ground Systems Progress

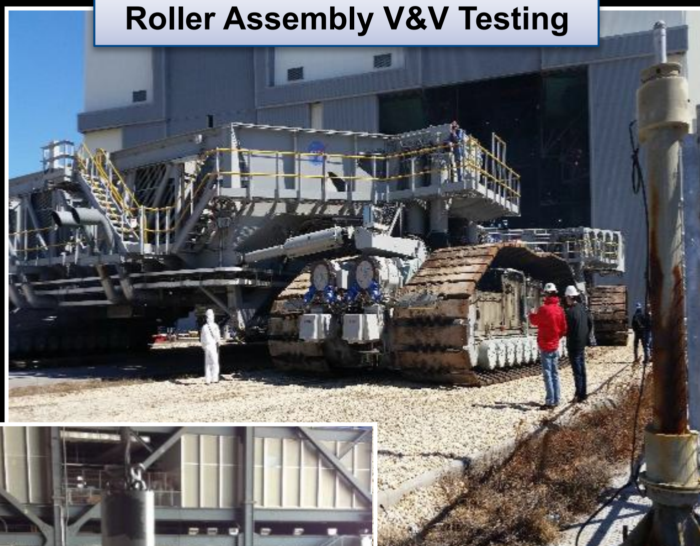
Vehicle Assembly Building

Fire Protection Systems

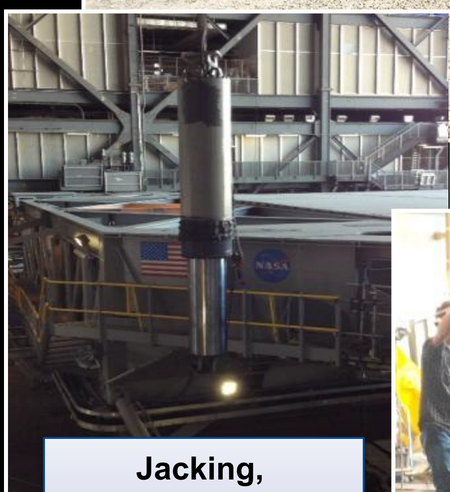
Cranes

Ground Systems Progress

Crawler Transporter



Roller Assembly V&V Testing

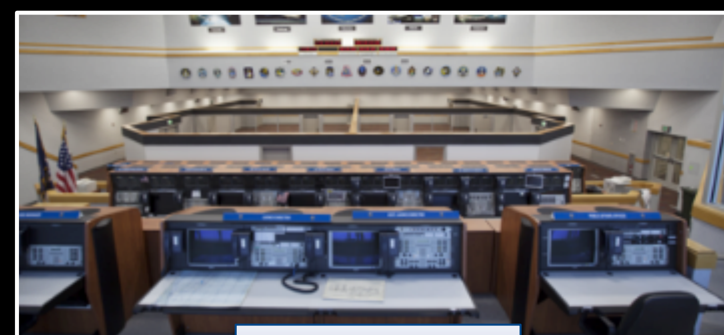


Jacking, Equalization & Leveling Cylinder Upgrades

Gearbox Refurbishment

Launch Control Center

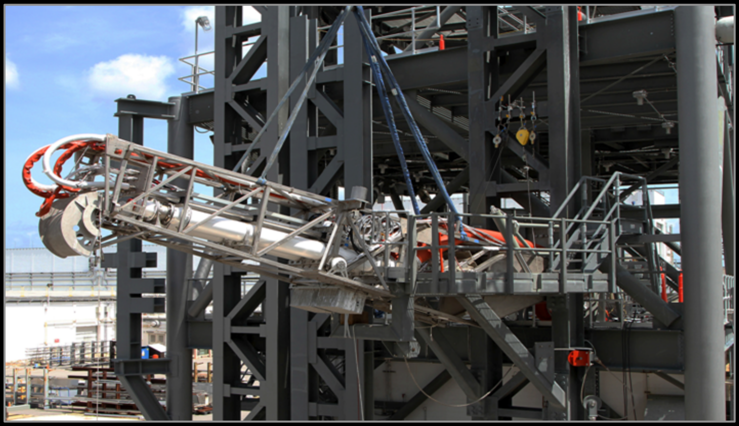
Control Room 1



Control Room 4

Ground Systems Progress

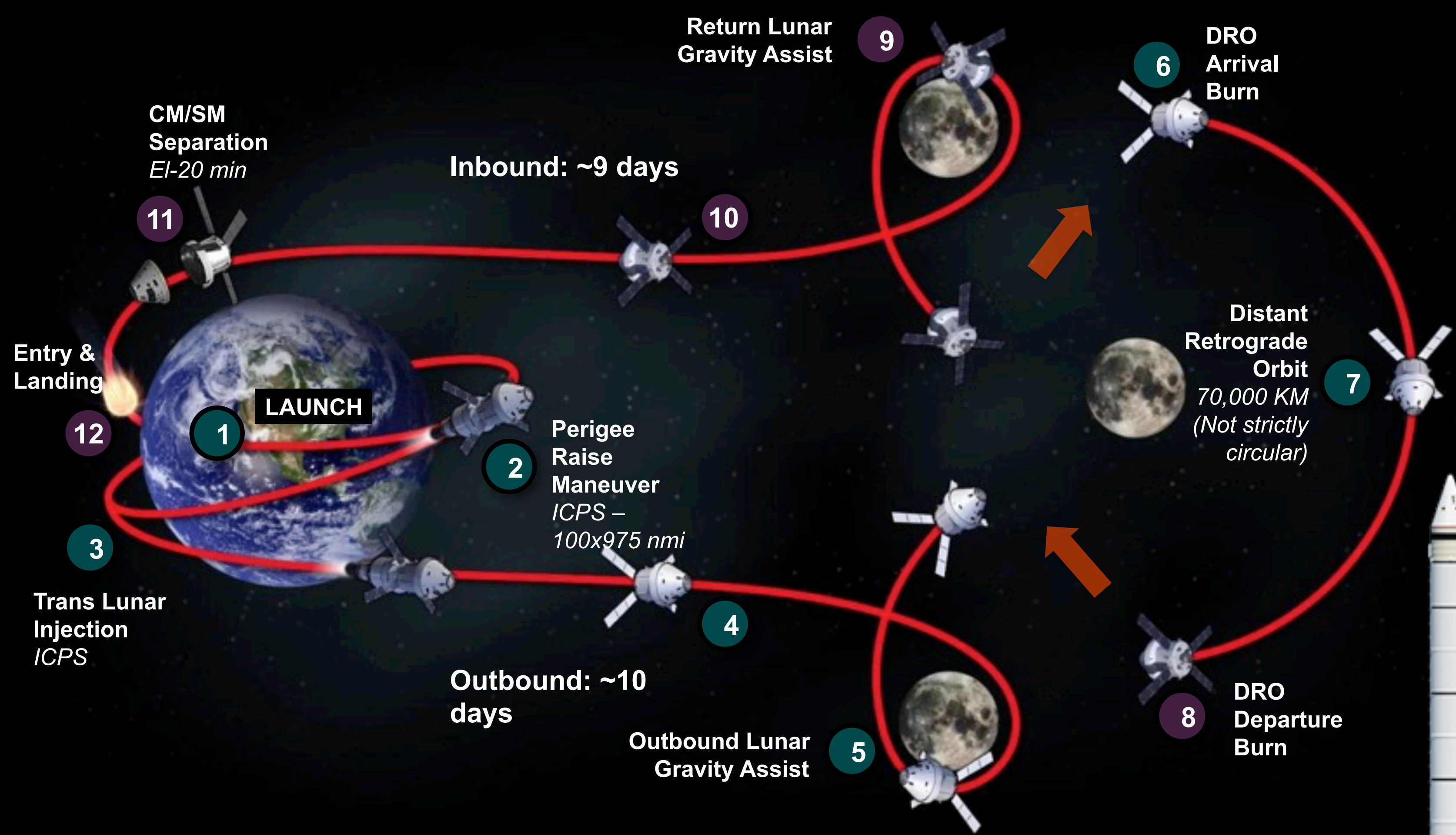
Mobile launch structural modifications are complete. Ground subsystem installation contract award planned for August.



The Orion Service Module Umbilical (OSMU) is being installed at the Launch Equipment Test Facility. Testing begins in August.

Testing of the Aft Skirt Electrical Umbilical (ASEU) was successfully completed at the Launch Equipment Test Facility in June.

Explortion Mission 1: Uncrewed Distant Retrograde Orbit (2018)



Objectives:

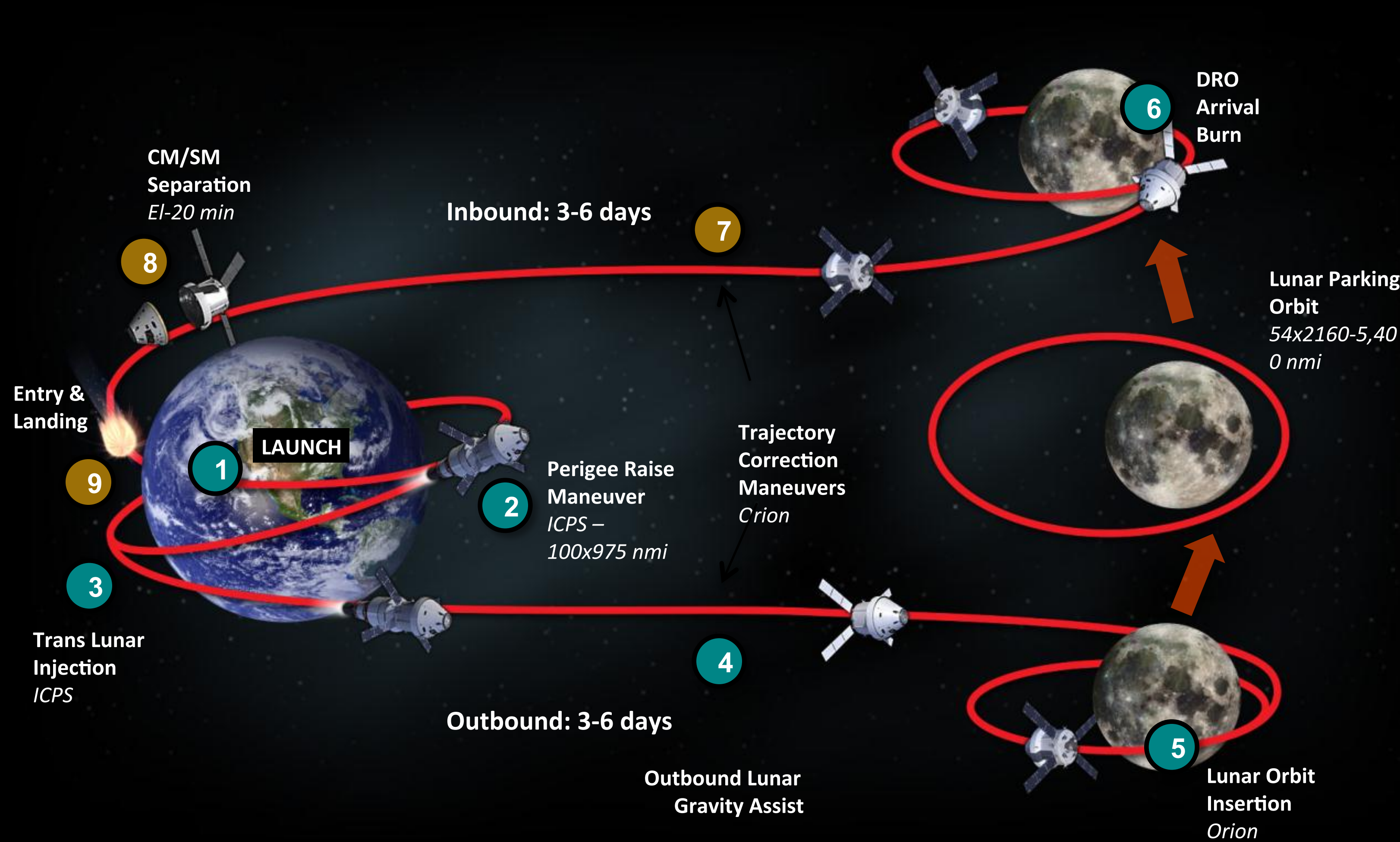
- Demonstrate spacecraft systems performance prior to crewed flight
- Demonstrate high speed entry (~11 km/s) and TPS performance prior to crewed flight

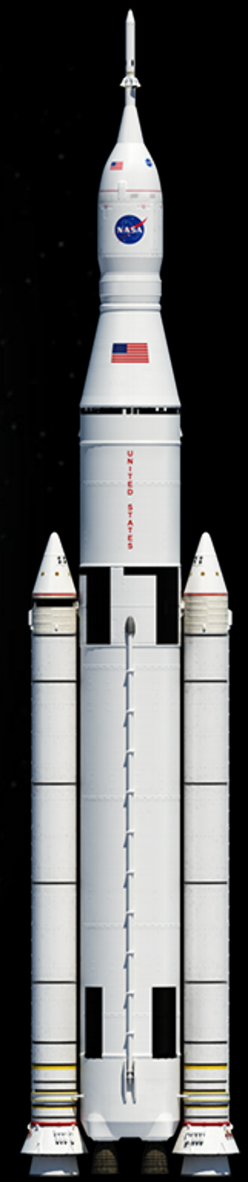
DRM - Uncrewed MPCV

- Lunar capable heat shield
- 4 tank SM with full prop load
- EM-2 systems not included: ECLSS, Crew Systems, LAS Abort Motors (Inert)

Interim Cryogenic Propulsion Stage (ICPS) used to provide TLI burn

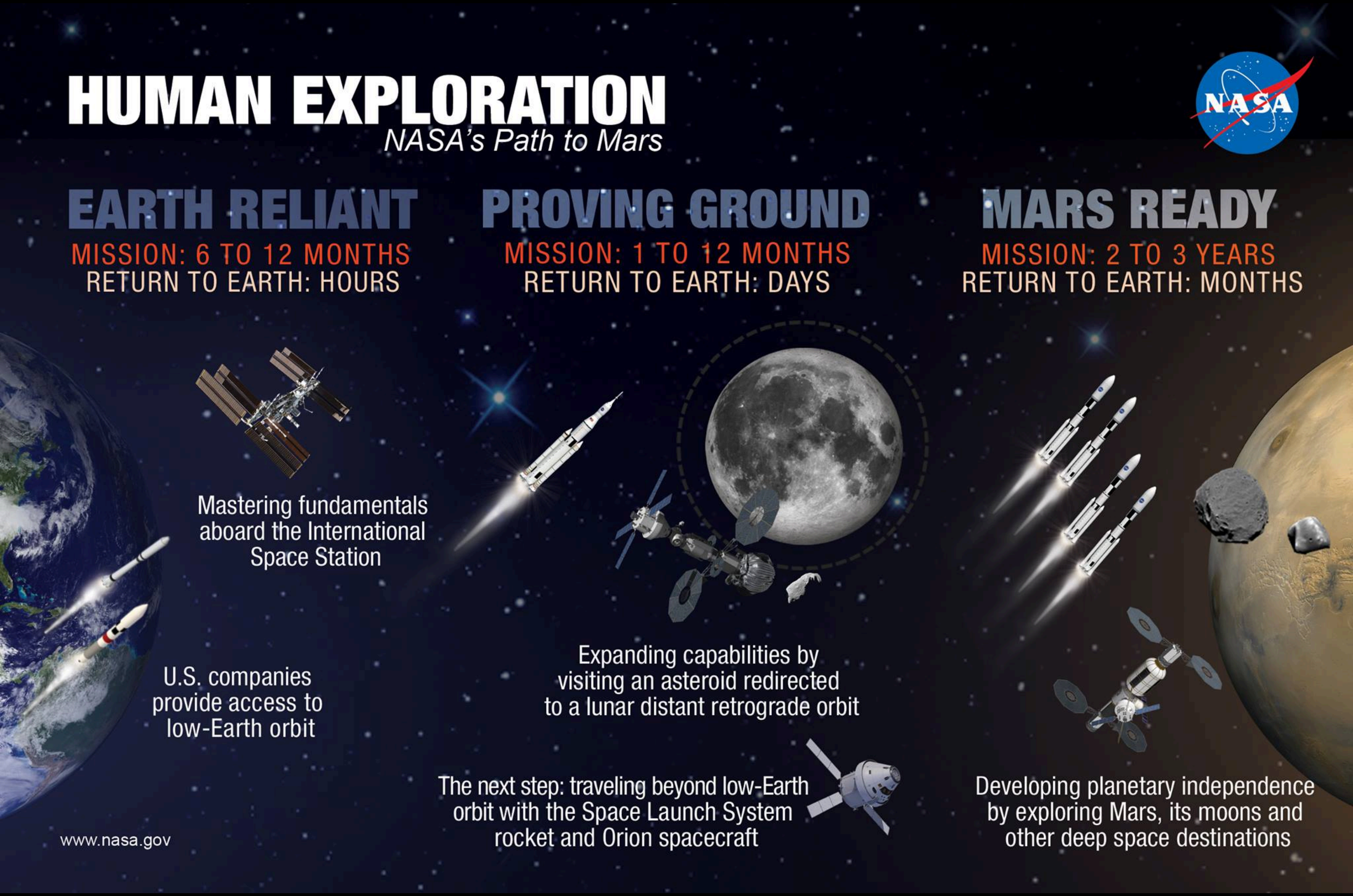
Exploration Mission-2 Crewed High Lunar Orbit (2021)





Objectives:
- Demonstrate crewed flight beyond LEO

DRM - Uncrewed MPCV
- Lunar capable heat shield
- 4 tank SM with full prop load
- Up to 4 crew



HUMAN EXPLORATION
NASA's Path to Mars
EARTH RELIANT
MISSION: 6 TO 12 MONTHS
RETURN TO EARTH: HOURS
PROVING GROUND
MISSION: 1 TO 12 MONTHS
RETURN TO EARTH: DAYS
MARS READY
MISSION: 2 TO 3 YEARS
RETURN TO EARTH: MONTHS
Mastering fundamentals aboard the International Space Station
U.S. companies provide access to low-Earth orbit
Expanding capabilities by visiting an asteroid redirected to a lunar distant retrograde orbit
The next step: traveling beyond low-Earth orbit with the Space Launch System rocket and Orion spacecraft
Developing planetary independence by exploring Mars, its moons and other deep space destinations
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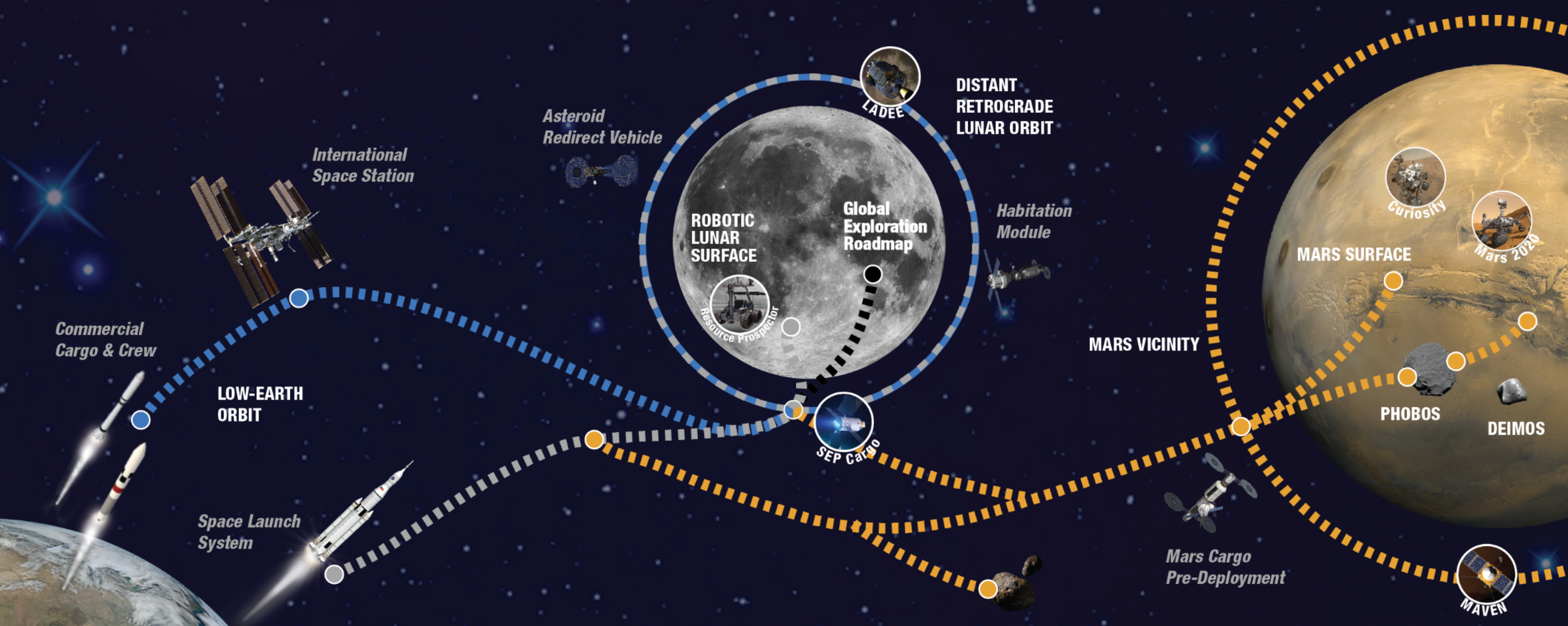
EVOLVABLE MARS CAMPAIGN

A Pioneering Approach to Exploration

EARTH RELIANT | PROVING GROUND | EARTH INDEPENDENT



THE TRADE SPACE

Across the Board | Solar Electric Propulsion • In-Situ Resource Utilization (ISRU) • Robotic Precursors • Human/Robotic Interactions • Partnership Coordination • Exploration and Science Activities

Cis-lunar Trades

- Deep-space testing and autonomous operations
- Extensibility to Mars
- Mars system staging/refurbishment point and trajectory analyses

Mars Vicinity Trades

- Split versus monolithic habitat
- Cargo pre-deployment
- Mars Phobos/Deimos activities
- Entry descent and landing concepts
- Transportation technologies/trajectory analyses

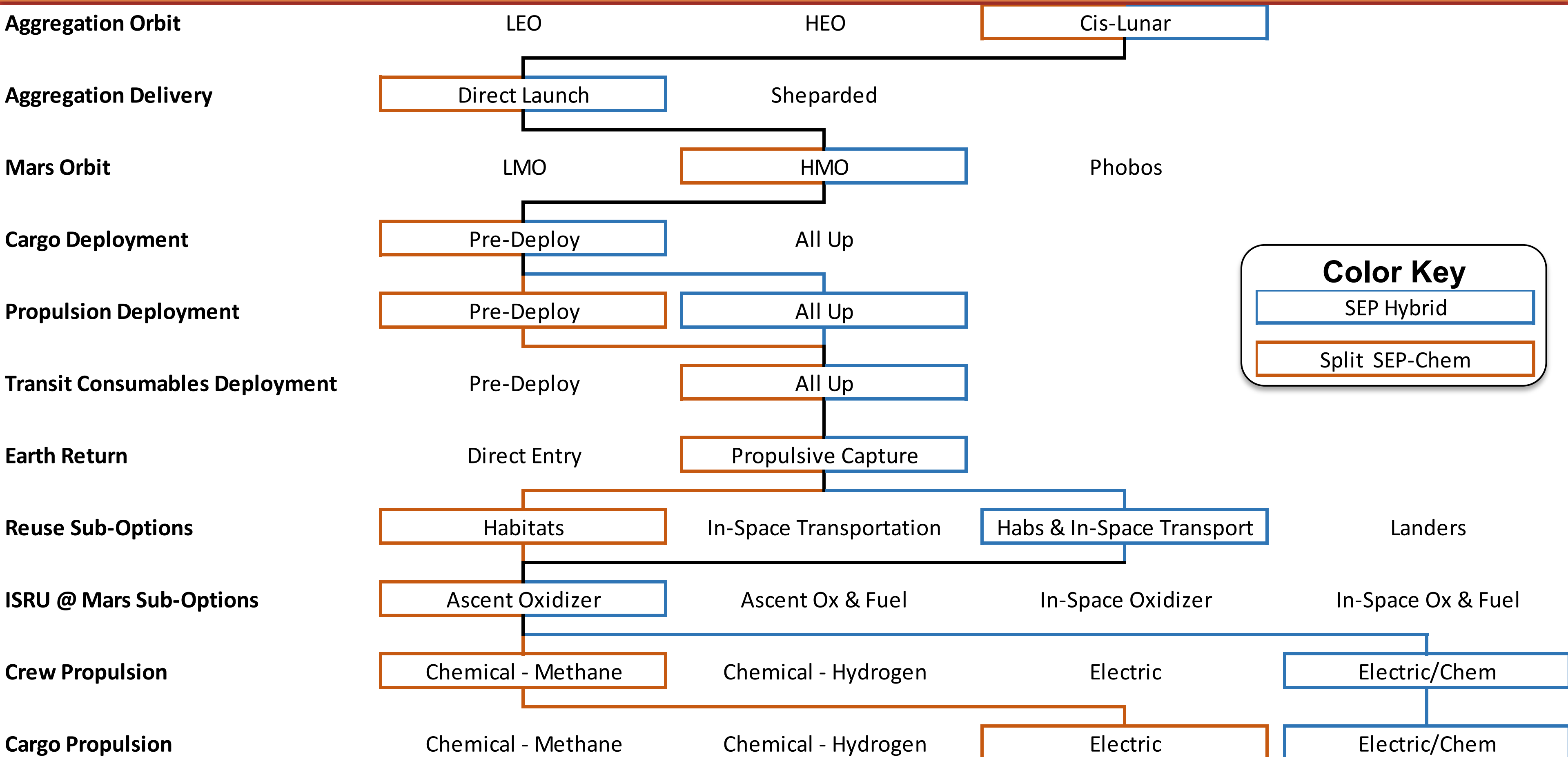
Mars Mission Analysis - Definition Trade Space

Mission Type	Flyby	Short Stay	Long Stay	
Surface Mission	None	Minimal	Full	
Surface Campaign	Single-Site, Build-Up	Multi-Site, Independent		
Mars Capture Method	Propulsive Capture All	Aerocapture Some Cargo	Aerocapture All Cargo	Aerocapture All
Reuse	None	Partial	Full	
ISRU	None	At Mars	At Earth	
Primary In-Space Propulsion	Chemical	Electric	Electric/Chem	NTP

EMC is one of 2592 possible paths in this tree

This is the box that EMC occupies in the global Mars Architecture trade space; what makes EMC unique

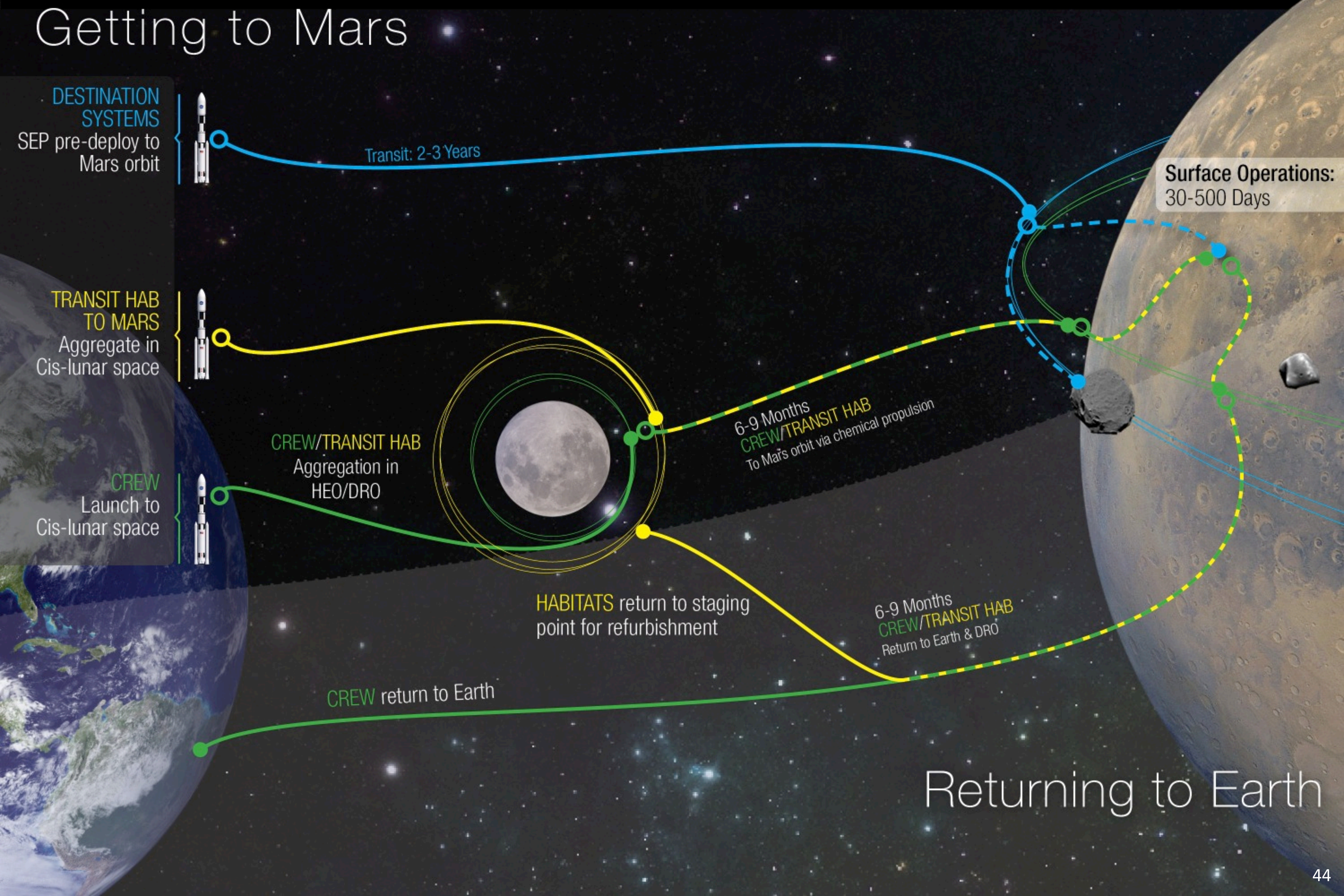
Mars Mission Analysis - Operational Trade Space



This is the level where we distinguish between Split SEP-Chem and SEP Hybrid

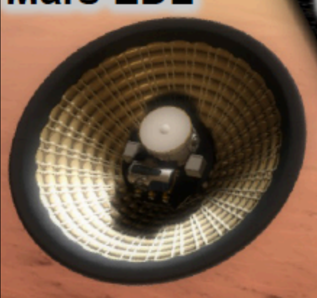
Approximately one of 74000 possible paths

Split Mission Concept (Current Concept)



In-Space Transportation

Mars EDL



Deliver crew and cargo to Mars surface

- ✓ Possible aerocapture at 6.3 km/s if not propulsively delivered to orbit
- ✓ Entry velocity of 3.8 – 4.7 km/s
- ✓ 100 m precision landing with hazard avoidance
- ✓ Supersonic retropropulsion with LOX/CH_4 engine
- ✓ Deployable/Inflatable (16-23 m) entry systems
- ✓ Surface access at +2 km MOLA
- ✓ 20-30 t payload to the surface, 40-60 t arrival at Mars

Challenges

Transport crew and cargo to/from Mars vicinity

Provide access to Mars surface

Provide transportation within the Mars system

Uncrewed operations during deployment and between uses

Electric Propulsion

Deliver approx. 40-60 t to Mars orbit

200-kW class solar array system (BOL at 1 AU) using 30% efficient GaAs, triple junction solar cells

300 V array system converted to 800 V for EP and 28 V for spacecraft

ARRM-Derived Hall Thruster:

- ✓ Common Xe storage and feed system with 13.3 kW thruster
- ✓ Isp: 2000 s or 3000 s modes

Common Capabilities

Chemical Propulsion

Common LOX/CH_4 Pump-Fed Engine:

- ✓ Thrust: 25 klbf
- ✓ Isp: 355-360 s
- ✓ Up to 15 year lifetime
- ✓ 150-500 s burn time
- ✓ 5:1 throttling
- ✓ Near-ZBO storage with 90 K cryocooler

LOX/CH_4 Pressure-Fed RCS:

- ✓ Thrust: 100-1000 lbf; Isp: 320 s

SEP - Hybrid

Combined SEP and hypergolic propulsion system delivers crew and cargo to Mars vicinity

- ✓ 2 x 200-kW class arrays
- ✓ 1,100 days total trip mission time, 300 days at Mars
- ✓ >16 kW thermal rejection
- ✓ Ability to refuel 24 t of Xe on orbit
- ✓ 15 year lifetime, 3 uses, 3 refuelings

Mars Ascent

Return crew and cargo from Mars surface

- ✓ 4 crew and 250 kg payload from ±30 deg latitude, 0 km MOLA to Mars parking orbit
- ✓ 26 t prop (20 t O_2, 6 t CH_4), 35 t total liftoff mass, 8 t Earth launch dry mass
- ✓ Up to 3 days flight duration
- ✓ 5 years dormant before use
- ✓ Use of ISRU-produced oxygen

Mars Taxi

Transport crew and cargo within the Mars system

- ✓ 4 crew for up to 2.5 days
- ✓ 7 t inert mass, 14 t wet mass
- ✓ 8 kW EOL at Mars solar power
- ✓ Reusable and refuelable

SEP - Chemical

SEP delivers cargo to Mars vicinity, and LOX/CH_4 propulsion delivers crew to/from Mars vicinity

- ✓ 1 x 200-kW class solar array
- ✓ >8 kW thermal rejection
- ✓ Flight times to Mars approx. 1,400 days
- ✓ 4-6 years dormant before use

Summary

- **Significant progress has been made in the SLS, Orion, and GSDO programs**

- **ESD Programs are on track for 2018 flight**
  - Hardware production, assembly, and testing are in progress

- **"Journey to Mars" trades and mission analysis are in progress**
  - Used to identify near-term mission content and technology requirements

www.nasa.gov/marshall